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# Application of aerobic biological filter for treating swine farms wastewater

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**Abstract**

In this paper, aerobic biological filter is applied to treat swine farms wastewater. Laboratory experiments are conducted to confirm the optimum parameters for start-up and operation of filter by investigating the effect of temperature on the start-up of the filter and the influence of temperature, pH value and recirculation rate on the treatment effect of the filter. The results show temperature increasing is benefit for accelerating start-up of filter in the range of 17.0-33.0℃. COD removal of the filter enhances slightly by temperature rising during normal operation. High $NH_3$-N reduction (above 84.0%) is obtained in range of 25.0-30.0℃. pH in range of 7.1-8.0 is recommended for operation treatment, in which pollutants reduction for COD and $NH_3$-N is 85.7%-86.9 and 86.8%-89.5%, respectively. COD and $NH_3$-N reduction enhances with recirculation rate increasing. When the recirculation rate is above 4, the increasing of COD and $NH_3$-N reduction is slight. Swine wastewater treatment project utilizing aerobic biological filter as a key element is established in a swine breeding farm of Daxing district, Beijing. The whole project runs well by start-up and operation of filter. COD reduction of wastewater in aerobic biological filter is 63.0-89.3%. And the COD concentration of effluent in filter is below 150mg/L, which achieves the national requirement of pollutants output standard of livestock and poultry breeding industry and water quality standard of farmland irrigation. The aerobic biological filter is worth to be generalized for treating swine wastewater in China.

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Keywords: Swine farms wastewater; Aerobic biological filter; Start-up; Operation parameters

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## 1. Introduction

In recent years, swine breeding industry in China has developed rapidly. The large scale intensive swine farms satisfy the demands of peoples for meat product, however, they results in large volumes of wastewater in small region, which takes serious pollution to the environment nearby [1-2]. According to estimation, the average annual manure and urine production amounts of a pig is 2.5t. At lest 30 thousand tons of wastes are poured into the environment in an intensive 10 thousand heads swine farm every year. And the daily wastewater amount is 100-150 tons whose COD content is 6000-10200mg/L and $BOD_5$ content is 3500-6000mg/L [3]. According to investigation, most of the intensive swine farms are lack of efficient wastewater treatment and integration utilization facilities [4]. The raw swine farms wastewater has high concentrations of organic matters, SS and $NH_3$-N. Beside, it also contains virus and protozoan pathogens which can cause disease in both of animals and humans [5]. An efficient and economical swine farms wastewater treatment method is needed urgently for sustainable developments of modern swine breeding industry and environment protecting.

Generally, there are three models of swine wastewater treatment. That is land spreading, natural treatment and engineered treatment. Land spreading and natural treatment have the features of investing saving and low operation costs, but lots of lands are needed. So, they are suitable for traditional and small scale swine farms wastewater treatments. For land limited large scale intensive swine farms, engineered treatment which includes aerobic, anaerobic and combined treatment is recommended [6].

During the last 20 years, aerobic treatment such as activated sludge, intermittent-cycle extended-aeration treatment, rotating biological contactors, and oxidation ditches treatment are widely utilized for swine wastewater treatment and obtain good reduction of COD and $NH_3$-N [7-13]. But the energy cost of traditional aerobic treatment is high, the operation skill is complex and operation cost and investing fee are expensive which restrict the application to swine wastewater treatment [14-15].

Aerobic biological filter is a new type biofilm fixed reactor. The filter contains fixed media which has a large surfaces area. The microorganism attaches on the surface of media and grows up to biofilm for removing pollutant efficiently [16-17]. With the characteristics of high adaptability to wastewater, less slurry production, easy maintenance and energy saving, aerobic biological filter is widely utilized for domestic wastewater [18], food process wastewater [19], aquiculture wastewater [20-22] and industry wastewater treatments [23-24]. But few reports are found on using aerobic biological filter for swine farms wastewater treatment. So, this paper reports the application of aerobic biological filter for swine wastewater treatment. Investigating the effect of temperature on the start-up of the filter, further, researching the influence of temperature, pH value and recirculation rate on the treatment effect of the filter. Then confirm the optimum parameters for filter start-up and operation. By monitoring and analyzing the operation of aerobic biological filter in swine breeding farm in Daxing district, Beijing, a new method is provided for swine farms wastewater treatment.

## 2. Material and methods

### *2.1. Reactor description*

In laboratory experiment, aerobic biological filter is made to square body (length=130mm, Height=1000mm) using PVC plastic board as material. The media for the filter is semi-soft plastic media with $220m^2/m^3$ surfaces area developed by ourselves. The filling depth of the media is 900mm. The filter adopts fixed nozzles uniform water distribution system. The wastewater is promoted to water distribution installation for distribution by mini-pump. The recirculation installation is set between the filter and influent tank. During the experiment process, water temperature is controlled by constant temperature water bath.

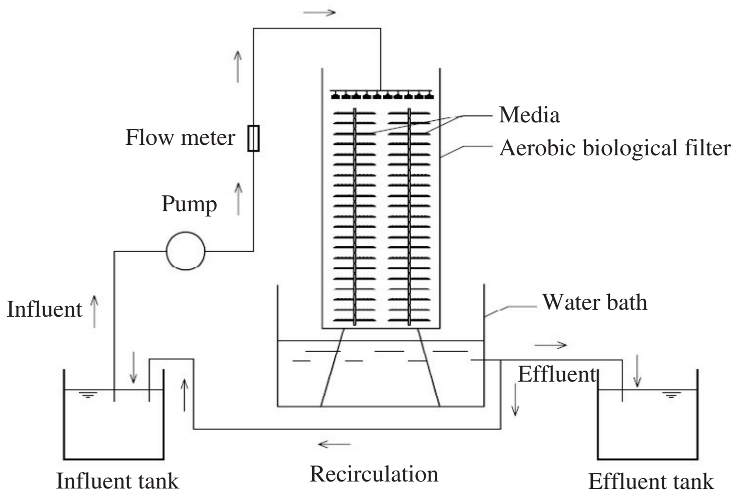


Fig.1 Schematic diagram of experiment installation

### 2.2. Experimental wastewater

For ensuring the wastewater quality uniform controlled, the wastewater in laboratory experiment is confected using swine manure collected from swine farm in Daxing district, Beijing. The characteristics of confected wastewater are summarized in Table 1.

Table1 Characteristics of test wastewater

| COD(mg/L) | $NH_3$-N(mg/L) | pH |
|---|---|---|
| 973.2-2728.8 | 70.5-243.2 | 7.3-8.2 |

### 2.3. Experiment design

For investigating the effect of temperature on the start-up of the filter, three treatments are set. The water temperature for treatment 1, treatment 2 and treatment 3 is 17.0-19.5℃, 25.2-27.0℃and 31.0-33.0℃, respectively. Other operation conditions for the three treatments are same. That is recirculation rate controlled at 5, hydraulic retention time (HRT) 24h. Every treatment keeps inputting synchronization and the quality of every influent is same.

After the optimum parameters of start-up being identified, the optimum operation parameters of filter are researched. This test is taken after the aerobic biological filter starting successfully. The influence of temperature, pH value and recirculation rate on the removal effect of the filter is analyzed. This test is divided into three stages. During each test stage, the operating conditions of the filters are summarized as follows:

Stage one (For analysis the influence of temperature on pollutants removal): The hydraulic load of filter is controlled at 0.9-1.1$m^3$/ ($m^3$ · d), recirculation rate 5, hydraulic retention time (HRT) 24h, influent pH 7.3-8.2. Influent temperature is controlled by constant temperature water bath which makes the temperature gradually rising with the range of 20.5-35.7℃. Every test is carried out after the temperature stabilization.

Stage two (For analysis the influence of pH value on pollutants removal): The hydraulic load of filter is controlled at 0.9-1.1$m^3$/ ($m^3$ · d), temperature 25.0-28.7℃, recirculation rate controlled 5, hydraulic retention time (HRT) 24h.

1% NaOH and 2% $H_2SO_4$ solution are added into influent for adjusting the pH value gradually rising with the range of 5.0-10.1.

Stage three (For analysis the influence of recirculation rate on pollutants removal): The hydraulic load of filter is controlled at 0.9-1.1$m^3$/ ($m^3 \cdot d$), temperature 25.0-28.7℃, hydraulic retention time (HRT) 24h, influent pH 7.3-8.2. The recirculation rate gradually rises with the range of 1-8.

### 2.4. Analytical methods

The chemical oxygen demand (COD) and ammonium nitrogen ($NH_3$-N) of influent and effluent of the filter are analyzed according to standard methods [25]. Additionally, the temperature and pH were routinely monitored during the experimental period.

## 3. Results and discussion

### 3.1. Influence of temperature on the start-up of aerobic biological filter

In the initial period of filter operation, part of wastewater, pollutants and bacterium attach on the surface of media by wastewater rushing through the media. Microorganism rears largely on the surface of media and a flat of film fully with microorganism is formed, which is called biofilm. This beginning phase is normally called start-up which is the mature period for biofilm. And only after the start-up process finishing, filter can be used for normal operation [26]. The factors of affecting biofilm growth are many, such as surface character of media, temperature, pH and so on. This test aims at semi-soft plastic media with 220$m^2/m^3$ surfaces area and mainly investigates the influence of temperature on the start-up of aerobic biological filter. And the start-up is considering being success when the removal rates of COD and $NH_3$-N are constantly more than 60% and 70%, respectively.

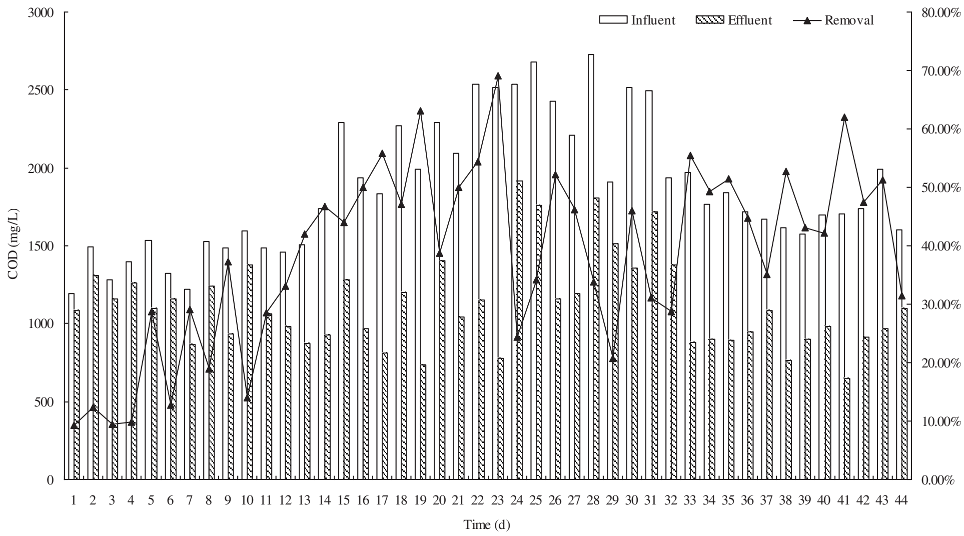


Fig.2 Influent and effluent COD at start-up phase in treatment 1

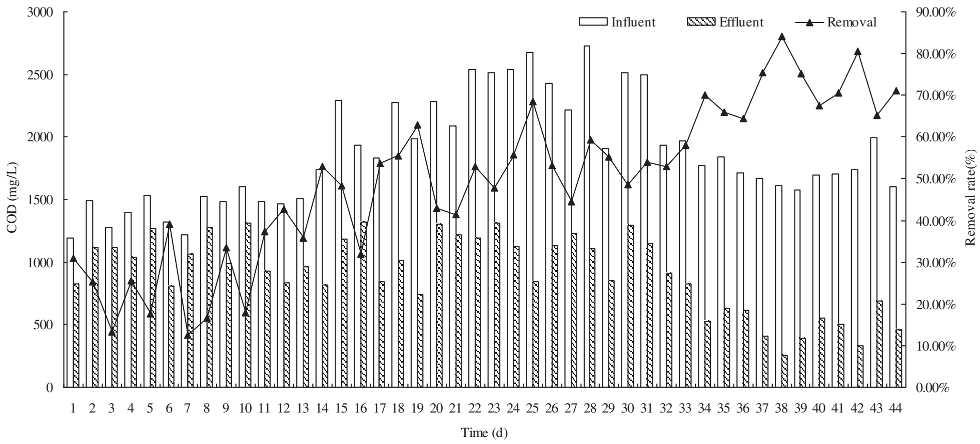


Fig.3 Influent and effluent COD at start-up phase in treatment 2

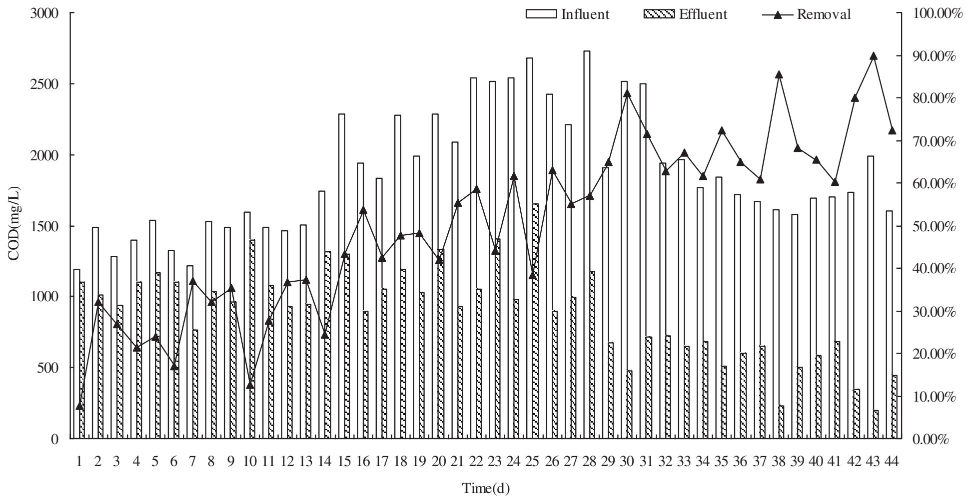


Fig.4 Influent and effluent COD at start-up phase in treatment 3

The COD of influent and effluent in three treatments are presented in Figs.2-4. As shown in Fig.2, the removal of COD of treatment 1 is very low (most of time below 60.0%) and the removal effect is not constant during the test period. The removal effect of treatment 2 and treatment 3 is also very low during the first 14d (See Fig.3-4). And the removal of COD rises from the 15thday. It indicates that the microorganism in both treatments is accumulating and adapting to the wastewater during the first 14d. The COD reduction of treatment 2 is more than 60.0% constantly after 33d operation and the highest removal achieve 84.1%. But in treatment 3, only after 28d, COD reduction achieves 60% constantly and the highest reduction is 89.9%.

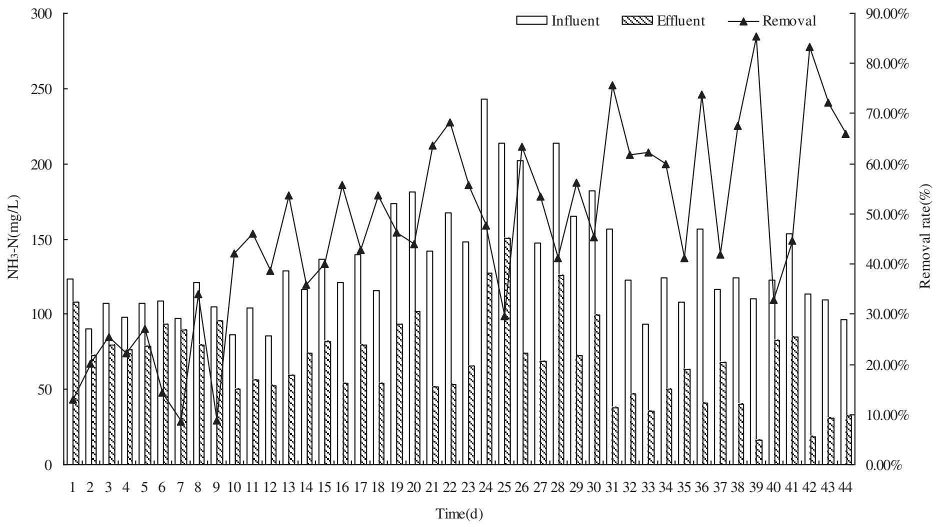


Fig.5 Influent and effluent $NH_3$-N at start-up phase in treatment 1

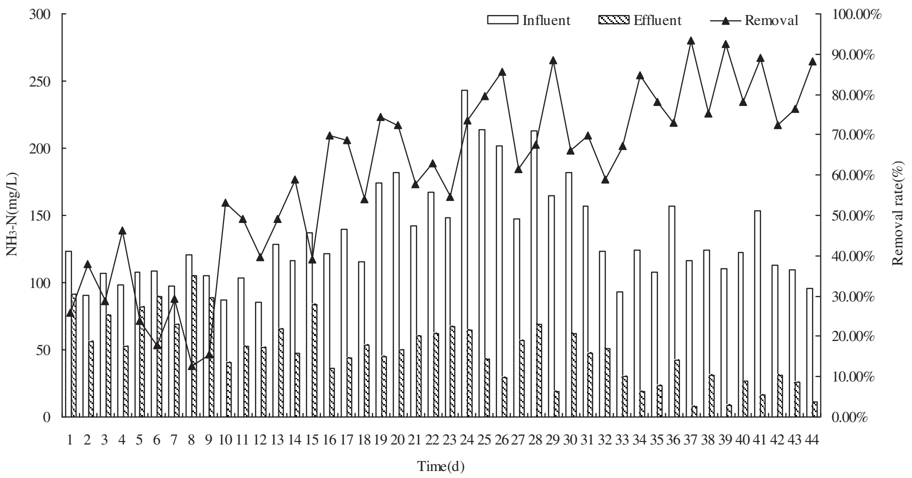


Fig.6 Influent and effluent $NH_3$-N at start-up phase in treatment 2

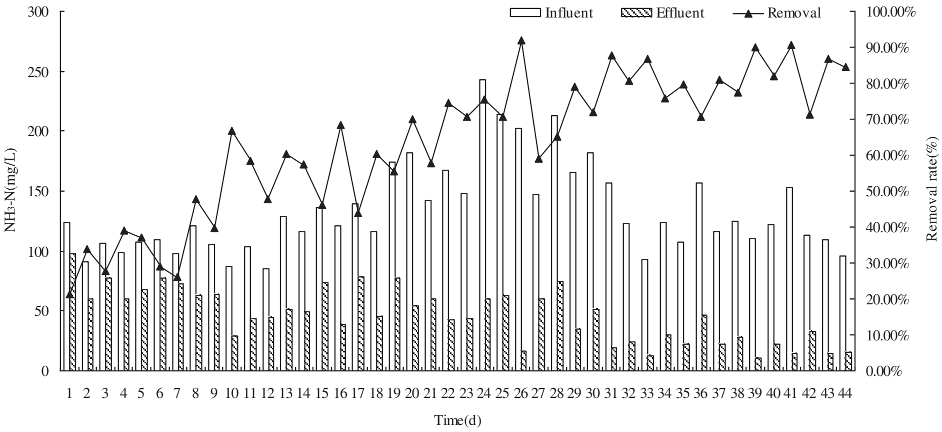


Fig.7 Influent and effluent $NH_3$-N at start-up phase in treatment 3

Fig.5-7 shows the $NH_3$-N reduction of three treatments. The $NH_3$-N removal of treatment 1 has a rising trend in first 10d. After 10thd, the reduction is basically more than 30%, but the changing range of reduction is big (29.7%-85.5%). The reduction is not constant (See Fig.5). The $NH_3$-N removal of treatment 2 increases remarkably from 7th -10th d. Then, the reduction enhances slowly. After 33d, $NH_3$-N reduction of treatment 2 is more than 70% (See Fig.6). Fig.7 represents that $NH_3$-N reduction of treatment 3 is more than 39.0% after 7d operation. After 28 d, $NH_3$-N reduction is above 70.0% stably and the highest reduction is 90.8%.

Treatment 1 is not start-up successful in 44d operation. The start-up of treatment 2 succeeds after 33d. But in treatment 3, only 28d is needed for start-up. It reflects that temperature rising has effect on filter start-up. In a certain range, high temperature induces a short time for filter start-up.

### *3.2. Influence of temperature on the operation of aerobic biological filter*

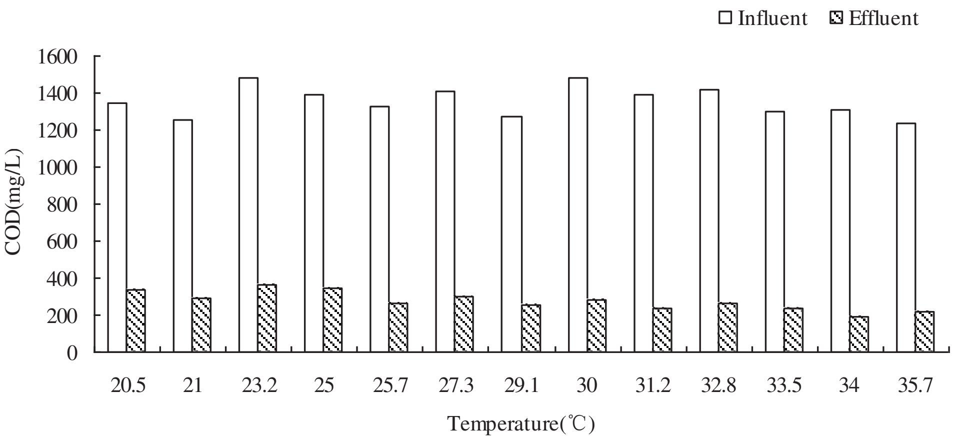


Fig.8 Influent and effluent COD in filter at different temperture

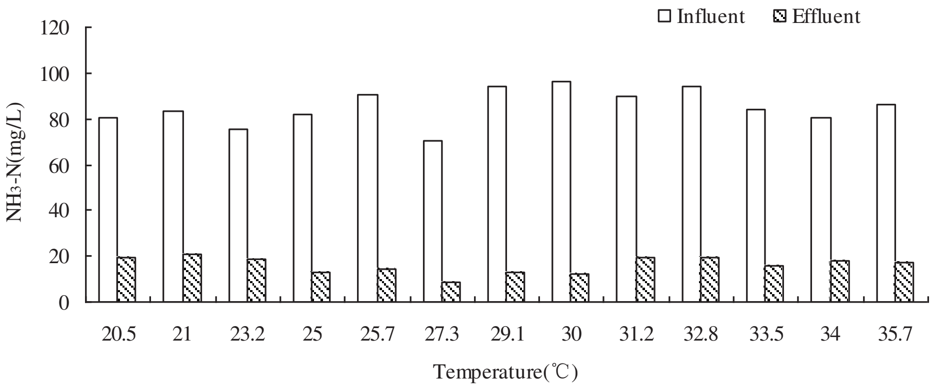


Fig.9 Influent and effluent $NH_3$-N in filter at different temperture

Table 2 COD and $NH_3$-N removal in filter at different temperture

| Temperature(℃) | COD removal (%) | $NH_3$-N removal (%) |
|---|---|---|
| 20.5 | 75.1 | 76.2 |
| 21.0 | 76.8 | 74.6 |
| 23.2 | 74.6 | 75.5 |
| 25.0 | 75.4 | 84.3 |
| 25.7 | 80.3 | 84.0 |
| 27.3 | 78.6 | 87.5 |
| 29.1 | 80.1 | 86.0 |
| 30.0 | 81.2 | 87.2 |
| 31.2 | 83.3 | 78.6 |
| 32.8 | 81.5 | 79.0 |
| 33.5 | 81.8 | 81.1 |
| 34.0 | 85.6 | 77.9 |
| 35.7 | 82.0 | 80.2 |

Temperature is one of the important factors for microorganism metabolizing. In some temperature range, metabolism activities of most microorganism reinforce with temperature rising or weaken with temperature declining. The suitable temperature range of aerobic microorganism is 10-35℃. Normally, temperature below 10℃ induces negative effect on biological treatment [27].

Influence of temperature on the COD of influent and effluent is shown in Fig.8. When the temperature changes with the range of 20.5-35.7℃,although COD concentration of influent fluctuates from 1236.8 mg/L to 1478.5mg/L, COD concentration of effluent is below 400mg/L which achieves the pollutants output standard of livestock and poultry breeding industry in China. And COD reduction increases with temperature rising.

Fig.9 reflects the influence of temperature on the $NH_3$-N of influent and effluent. When the temperature changes with the range of 20.5-35.7℃, the effect of temperature on $NH_3$-N reduction is remarkable. Comparing with temperature at 25.0-30.0℃, the reduction of $NH_3$-N is lower at temperature below 25.0℃ (shown in Table 2). At

25.0-30.0℃, the $NH_3$-N concentration of effluent is also very low (below 15mg/L). $NH_3$-N reduction decreases slightly at temperature above 30.0℃. By analysis, it is because that temperature changing has great effect on the specific growth rate and activity of nitrifying bacteria. Temperature at 25.0-30.0℃ is suitable for nitrifying bacteria growth [28] and nitrification rate increases which is beneficial to $NH_3$-N reduction. When the temperature is above 30.0℃, protein denaturation reduces the activity of nitrifying bacteria. And nitrifying bacteria grows slowly which declines $NH_3$-N reduction [29]. For obtaining good treatment effect, 25.0-30.0℃ is recommended for the operation temperature of aerobic biological filter.

### *3.3. Influence of pH on the operation of aerobic biological filter*

Normally, the optimum pH is 6.0-8.0 for microorganism growth. The value of pH exceeding this range will result in negative effect on microorganism activity. As listing in Table 3, when the pH changes with the range of 5.0-8.0, COD removal gradually increases with pH rising. The best COD removal (removal rate=86.9%) is obtained at pH 8.0. And COD removal declines significantly at pH above 8.0. So, the optimum pH range for COD reduction is 7.1-8.0. In this period, the removal rate is more than 85%. And when pH value is below 7.1 or above 8.0, COD reduction will decrease. That is due to inner of cell membrane expressing alkaline. Most of microorganism can survive well in neutral or alkaline condition. The value of pH expressing acidity can weaken the alkaline state inside of cell membrane, which reduces the pH grads in both sides of cell membrane and breaks the energy balance for maintaining the microorganism growth. Excessive alkalescence also hinders microorganism growth [30].

Fig.11 indicates that $NH_3$-N reduction increases gradually with pH enhancing. When pH is 5.0, $NH_3$-N reduction is lowest (75.8%). And when pH is 10.1, $NH_3$-N reduction is highest (95.2%). It is because that acidity-alkalinity is an important impact on nitrification [31]. The optimum pH range for nitrification is 7.5-8.0[32-33]. And according to the ionization balance of $NH_4^+$（$NH_3+H^+ \rightarrow NH_4^+$）, when the pH at alkaline condition, the balance will forward to the side of NH3 concentration increasing, which is beneficial for $NH_3$-N reduction.

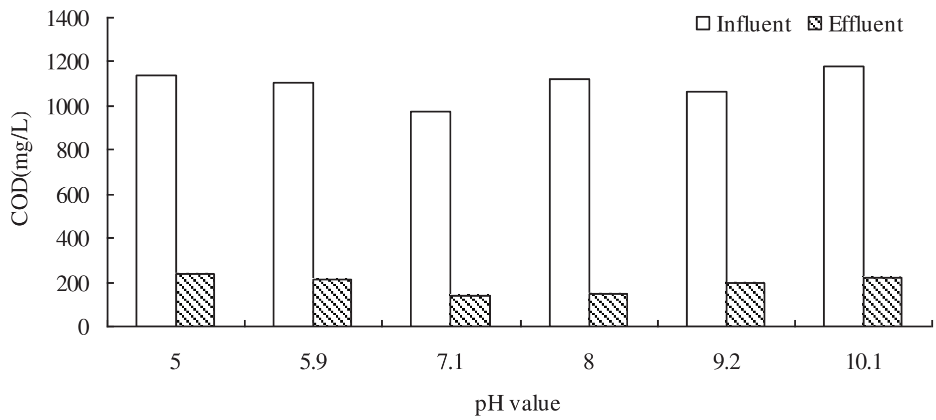


Fig.10 Influent and effluent COD in filter at different pH value

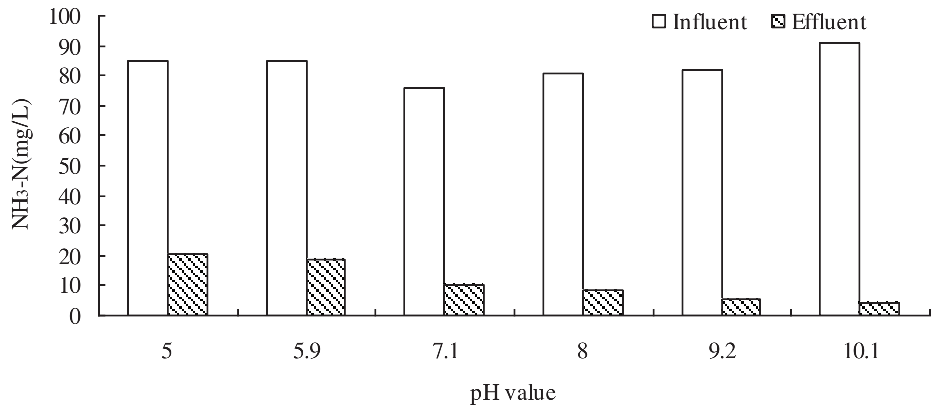


Fig.11 Influent and effluent $NH_3$-N in filter at different pH value

Table 3 COD and $NH_3$-N removal in filter at different pH value

| pH value | COD removal (%) | $NH_3$-N removal (%) |
|---|---|---|
| 5.0 | 79.2 | 75.8 |
| 5.9 | 80.4 | 78.2 |
| 7.1 | 85.7 | 86.8 |
| 8.0 | 86.9 | 89.5 |
| 9.2 | 81.7 | 93.3 |
| 10.1 | 81.4 | 95.2 |

### *3.4. Influence of recirculation rate on the operation of aerobic biological filter*

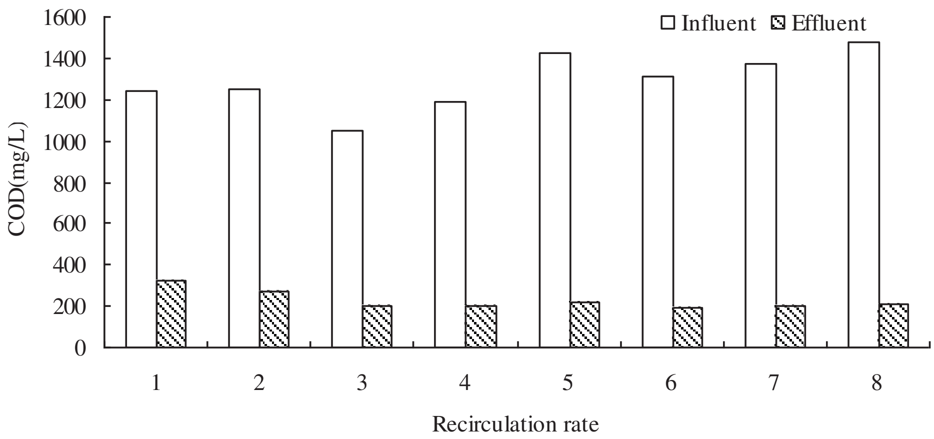


Fig.12 Influent and effluent COD in filter at different recirculation rate

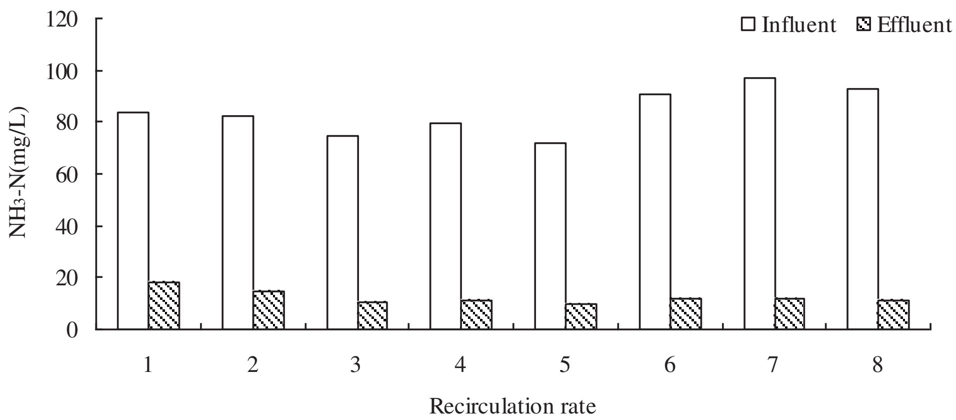


Fig.13 Influent and effluent $NH_3$-N in filter at different recirculation rate

Table 4 COD and $NH_3$-N removal in filter at different recirculation rate

| recirculation rate | COD removal (%) | NH3-N removal (%) |
|---|---|---|
| 1 | 74.1 | 78.6 |
| 2 | 78.6 | 82.1 |
| 3 | 80.5 | 85.9 |
| 4 | 83.3 | 86.3 |
| 5 | 84.8 | 86.5 |
| 6 | 85.1 | 87.2 |
| 7 | 85.3 | 87.7 |
| 8 | 85.8 | 87.9 |

Recirculation method is usually adopted for water treatment in aerobic biological filter. There are many benefits for using recirculation, such as equalizing filter load, enhancing treatment efficiency and reducing odour of influent. The objective of the test is to investigate removal effect of pollutants in filter with recirculation rate range of 1-8.

As represented in Table 4, when the recirculation rate is 1, 4 and 8, the COD reduction is 74.1%, 83.3% and 85.8%, respectively. It illustrates COD removal improves significantly at recirculation rate increasing from 1 to 4. When the recirculation rate is above 4, COD reduction enhances slightly with recirculation rate increasing, which indicates the remainder organic matter in the recirculation water is difficult for degradation by increasing recirculation rate and COD removal of effluent is not easy for further improving [34]. The increasing of recirculation rate is not only diluting the influent but also prolonging the retention time and contacting time with microorganism for wastewater. But prolonging the retention time of wastewater can induce the volume of filter increasing. High recirculation rate increases the operation costs of water treatment projects [35-36]. So, proper recirculation rate is needed for enhancing pollutants removal of filter.

$NH_3$-N reduction increases slightly with recirculation rate enhancing. When the recirculation rate changes from 1 to 4, $NH_3$-N removal increases relatively quickly. For the recirculation rate changing from 4 to 8, the changes of $NH_3$-N reduction is small, which reflects $NH_3$-N reduction has few relations with the change of recirculation rate. It considers that dissolved oxygen carried in recirculation water is benefit to nitrification. But when the recirculation rate is above 4, the accelerating impacts of dissolved oxygen carried in recirculation water on nitrifying bacteria are to limit, which provides reference for confirming the optimum recirculation rate of projects operation.

*3.5. Research of aerobic biological filter applied in projects.*

*3.5.1. Site description*

By analysis the start-up of the aerobic biological filter and influence of temperature, pH value and recirculation rate on the treatment effect of the filter, parameters are provided for optimization of swine wastewater treatment. And aerobic biological filter technology is applied for swine breeding farm wastewater treatment for projects practice in Daxing district, Beijing.

Swine breeding farm in Daxing district is established in 1978 covering 17.3 hectares area, with 600 heads of base sow. Annual swine production is about 10 thousands heads. The manure cleaning technology of the farms are main dry manure clean, with water wash as complement. About 30 thousands tons of wastewater is poured every year with COD concentration above 6000mg/L.

*3.5.2. Wastewater treatment technology of the swine breeding farm*

According to the features of swine wastewater (high concentration, high SS and good sedimentation performance), wastewater is treated for solid-liquid separation, firstly. In this process, solid organic matters are separated and pollutants content of liquid reduces in order to release the difficulty of wastewater treatment. After composting, the separated solid is utilized to produce organic fertilizer for sale. Liquid parts are treated by combining treating model which is "sedimentation tank-hydrolytic acidification tank-recirculation tank-high rate aerobic biological filter-oxidation pond". (See Fig.14) The treated wastewater is mainly used for irrigating farmland and forests nearby, which achieves the efficient utilization of water resource.

The core part of the wastewater treatment project is aerobic biological filter. The media for the filter is semi-soft plastic media with 220m$^2$/m$^3$ surfaces area developed by ourselves. The filter adopts autorotation water distribution installation which depends on the reaction of water flow to driving horizontal pipes for uniform motion and sprinkles the wastewater uniformly to the entire filter. Rotating parts of water distribution installation adopts corrosion resistance material. The recirculation rate of the filter is 4 and ventilation systems are used in the filter, which efficiently enhances the removal of organic matter.

The whole wastewater treatment costs little energy and is easy for operation. The water heads are set between every element in the system for making wastewater circulating automatically between every technology phase. Total energy consumption of the project is about 36kW•h/d. The project achieves the automatic operation and control. Only one person is needed to observe and manage the project.

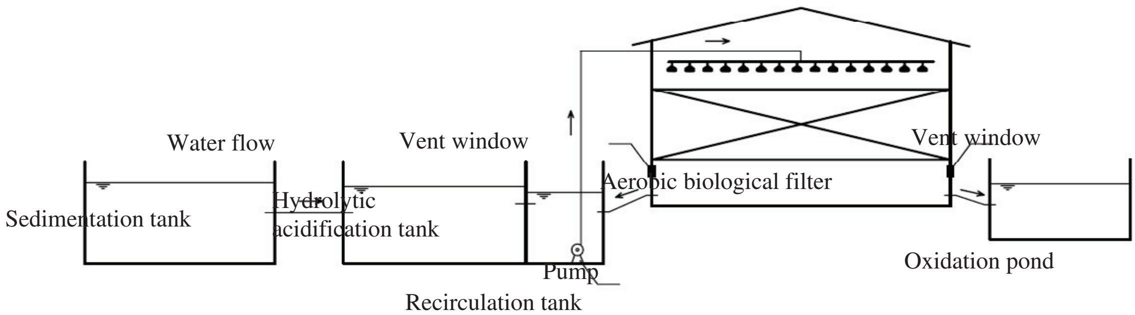


Fig.14 Schematic diagram of swine farm wastewater project using aerobic biological filter

*3.5.3. Operation effect*

The project starts in May, 2004. After about one month for operation and commissioning, the aerobic biological filter is successful start-up and operates well. The organic matter reductions of every treating element are tested after operating normally. The monitoring results are shown in Table 5.

Table 5 COD removal in the teatment project

| Piggery effluent | Sedimentation tank effluent | | Hydrolytic acidification tank effluent | | Aerobic biological filter effluent | | oxidation pond effluent |
|---|---|---|---|---|---|---|---|
| COD (mg/L) | COD (mg/L) | Removal (%) | COD (mg/L) | Removal (%) | COD (mg/L) | Removal (%) | COD (mg/L) |
| 5934.0 | 1109.7 | 81.3 | 309.6 | 72.1 | 88.5 | 71.4 | - |
| 7216.8 | 692.8 | 90.4 | 145.5 | 79.0 | 53.8 | 63.0 | - |
| 6695.0 | 1760.8 | 73.7 | 794.1 | 54.9 | 118.3 | 85.1 | 86.3 |
| - | 1873.8 | - | 905.0 | 51.7 | 96.8 | 89.3 | - |
| 7223.8 | 2094.9 | 71.0 | 1026.5 | 51.0 | 127.3 | 87.6 | 91.8 |
| - | 1964.0 | - | 893.6 | 54.5 | 118.9 | 86.7 | 90.0 |

Table 5 represents the COD removal of wastewater in sedimentation tank, hydrolytic acidification tank, and high rate aerobic biological filter is 71.0%-90.4%, 51.0%-79.0% and 63.0%-89.3%, respectively. The COD concentration of effluent in filter is below 150mg/L, which achieves the national requirements of pollutants output standard of livestock and poultry breeding industry (GB18596-2001) and water quality standard of farmland irrigation (GB5084-1992). The terminal effluent of project is used for irrigating farmland and forests nearby, which saves the water resource and the cost of irrigation.

## 4. Conclusions

Based on the results obtained above, the following conclusions can be made:

(1) With range of 17.0-33.0℃, temperature rising is benefit for shortening the start-up time of aerobic biological filter. Treatment 1(water temperature is 17.0-19.5℃) is not successful start-up in 44d operation. The start-up of treatment 2 (water temperature is 25.2-27.0℃) succeeds after 33d operation with COD reduction above 60% and $NH_3$-N removal above 70%. And 28d is needed for start-up in treatment 3 (water temperature is 31.0-33.0℃).

(2) COD removal enhances slightly with temperature rising at the range of 20.5-35.7℃.$NH_3$-N reduction of filter is above 84.0% at 25.0-30.0℃. The optimum temperature for operation is 25-30℃.

(3) The best COD removal (removal rate more than 85%) is obtained when pH value is in the range of 7.1-8.0. $NH_3$-N reduction increases with pH rising. The best $NH_3$-N reduction (reduction=95.2%) is achieved at pH 10.1. The optimum removal effect is obtained when the pH is in the range of 7.1-8.0.

(4) COD and $NH_3$-N reductions enhance with recirculation rate increasing. In the tests, when the recirculation rate is above 4, the increasing of COD and $NH_3$-N reductions are slight. So, recirculation rate at 4 is recommended for filter operation.

(5) The technology of "sedimentation tank-hydrolytic acidification tank-recirculation tank-high rate aerobic biological filter-oxidation pond" is utilized for wastewater treatment in swine breeding farm in Daxing district, Beijing. The monitoring results show that COD concentration of filter effluent is below 150mg/L and the effluent quality achieves the national requirements of pollutants output standard of livestock and poultry breeding industry (GB18596-2001) and water quality standard of farmland irrigation (GB5084-1992). The terminal effluent of project is used for irrigating farmland and forests nearby, which achieves the aim of resource conservation and promotes the sustainability of the whole project.

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